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Compensation of Long Term Voltage Fluctuations Using DVR with SMES

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ABSTRACT: Now a days power grid has been experiencing several disturbances in electric power generation, transmission, and distribution. Changing electric load and higher power transfer in a wide interconnected network leads to serious, security lack in power system operation. As energy storage appears to be beneficial to utilities since it can co-ordinate the instantaneous balance between demand and supply. Today, there is a demand for short term energy storage devices like flywheel energy storage, photovoltaic modules, battery energy storage and super capacitors. Since they are having less power and energy rating, they cannot be used for high power applications. So in order to minimize this problem, SMES has been used to improve power system performance as well as power quality as it has having high power rating with maximum efficiency. Super conducting magnetic energy storage (SMES) based dynamic voltage restorer (DVR) is introduced to protect consumers from the grid voltage fluctuations. Due to its high energy density and quick response, its is selected as the energy storage unit to improve the compensation capability of DVR. The operation principle of the SMES based DVR, and design of the DVR control method are explained here. In normal DVR based compensation, downstream fault current was not considered or the DVR was bypassed during that fault. But here along with voltage sag compensation, downstream fault current mitigation was also considered.Using MATLAB, the SMES based DVR is modelled, and the simulation tests are carried out to evaluate the system performance.

KEYWORDS: Downstream fault; DVR; SMES;Power Quality; Voltage Fluctuations

I. INTRODUCTION

Now a days, modern industrial equipments are mostly based on electronic devices such as programmable logic controllers. These electronic devices are very sensitive to power fluctuations and become less tolerant to power quality problems such as voltage swells, sags and harmonics. Voltage sags are considered to be one of the most severe disturbance to the industrial devices. Voltage compensation at a load can be achieved by proper reactive power injection at the load point of common coupling. Shunt capacitors can be used in the primary side of the distribution transformer for the compensation of reactive power and thereby for voltage compensation. Using SCADA the mechanical switching can be done with some timing schedule, or with no switching at all. The disadvantage is high speed transients cannot be compensated. Some sags are not corrected within the limited time .Transformer taps can be used, but its costly when using on load. Another solution existing to the voltage regulation is the use of a dynamic voltage restorer (DVR)[17] The operating principle of a DVR is to inject a voltage of required magnitude and phase in series with a feeder to maintain the desired amplitude and waveform for the load voltage to be compensated. In addition to that, the compensation capability is sensitive to the load level, and is independent of the system short circuit capacity and the installation position [1].It employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR are mainly used for sensitive loads that may be seriously affected by fluctuations in system voltage.

Voltage sags are becoming the most important power quality concern to electric utility customers with sensitive loads. Voltage magnitude between 0.1 to 0.9 Pu are said to be sags. Sags are predominantly caused by faults that are unavoidable on the distribution systems due to the interconnectivity of the utility systems. The distribution-class dynamic voltage restorer (DVR) is a series connected power electronics device which can compensate for distribution system sags and swell [21].Dynamic Voltage Restorer (DVR) is a custom device used in power distribution networks to solve the problems of voltage sags and swells and its severe impact on sensitive loads. DVR is a series connected solid-state device that injects appropriate voltage into the system in order to compensate the load voltage fluctuations. Its primary function is to rapidly boost up the load side voltage in the case of a disturbance in order to avoid any power disruption to that load [7]. Due to the characteristic of high energy density and quick response, a superconducting magnet is selected as the energy storage unit to improve the compensation capability of DVR [1][3]. A Superconducting Magnetic Energy Storage device consists power electronic converters that rapidly injects and/or absorbs real and/or reactive power and thereby controls power flow in an distribuition / transmission system. [2][5][7]

Superconducting Magnetic Energy Storage (SMES), characterized by its highly efficient energy storage, quick response, and power controllability, is expected to contribute to high-quality power of the power systems. SMES can be utilized in two efficient ways. One is utilizing it as a UPS or connect SMES parallel. The second method controls the system voltage indirectly through regulating the injecting current of SMES. The compensation capability is influenced by the system short circuit capacity and the location of SMES. To improve the compensation capability of DVR, such as a long duration voltage fluctuation, the energy storage unit is essential to supply the power transfer during the voltage compensation [1]. In this paper, a superconducting magnet is introduced as the energy storage unit of the DVR. Firstly, the operation principle of the SMES based DVR is analysed. Then, the dynamic response of the SMES based DVR is evaluated using MATLAB simulation.

II MODELLING OF DVR

Power quality concern is increasing now a days. Major power quality problems are voltage sag, voltage swells, harmonics, flickering etc. Voltage sag is the major problem that evolvs among the consumers. Custom power devices are introduced from the earlier days as an effective solution for this. DVR is the main custom power device for this voltage sag mitigation.Other than voltage sags and swells compensation, DVR can also compensate for line voltage harmonics,reduction of transients in voltage and fault current limitations.

A. *Basic Configuration of DVR*

The main components of the DVR consists of:

- Energy storage unit
- Filter unit
- Inverter circuit
- Series injection transformer

Energy storage unit

During a voltage sag, the DVR injects a voltage to restore the load supply voltages. The DVR needs a source for this energy. Two types of system are considered, one using stored energy to supply the delivered power and the other having no internal energy, where energy is taken from the incoming supply through a shunt converter. Fig 1 descibes the major components of DVR.

Inverter circuit

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The voltage source inverter converters the dc voltage from the energy storage unit to a controllable three phase ac voltage. The inverter switches are normally fired using a sinusoidal pulse width modulation scheme. Since the vast majority of voltage sags are seen on utility systems are unbalanced, the VSI will often operate with unbalanced switching functions for the three phase, and must therefore treat each phase independently. Moreover a sag on one phase may result in swell on another phase.

Filter unit

The non linear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output. To overcome this problem and provide high quality energy supply, a harmonic filtering unit is used. These filters can be placed in either side of the inverter.

Series injection transformer

Three single phase injection transformers are used to inject the missing voltage to the system at the load bus. To integrate the injection transformer correctly into the DVR, the MVA rating, the primary winding voltage and current ratings, the turns ratio and the short circuit impedance values of transformers are required. The existence of the transformers allow for the design of the DVR in a lower voltage level.

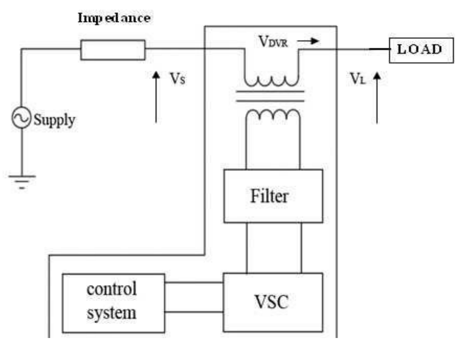

Fig. 1 Components of DVR

B. *Mathematical model of DVR*

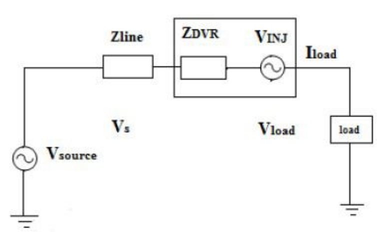

Fig. 2 Equivalent Circuit of DVR

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The system impedance depends on the fault level of the load bus. When the system voltage drops, the DVR injects a series voltage through the injection transformer so that the desired load voltage magnitude can be maintained. Fig 2 shows the equivalent circuit of DVR.The series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \quad (1)$$

$$V_{DVR} < 0 = V_L < 0 + Z_{TH} < (\beta - \theta) - V_{TH} < \delta \quad (2)$$

The complex power injection of the DVR can be written as,

$$S_{DVR} = V_{DVR} I_L \quad (3)$$

$$\theta = tan^{-1}(\frac{\theta_L}{P_L}) \quad (4)$$

The load current IL is given by,

$$I_L = \frac{[P_L + jQ_L]}{V} \quad (5)$$

III.SUPERCONDUCTING MAGNETIC ENERGY STORAGE(SMES)

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil. An SMES system consists of three parts: a superconducting coil, power conditioning system and a cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. This is the main property of SMES. Discharging of coil allow SMES to releases the stored charge. The power conditioning system uses an inverter/rectifier system to transform an alternating current (AC) power to direct current or convert DC back to AC power. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient and is greater than 95%.

Due to the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly meant to improve power quality. If SMES were to be used for utilities it would be a day to day storage device, that is charged from base load power at night and meeting peak loads during the day.

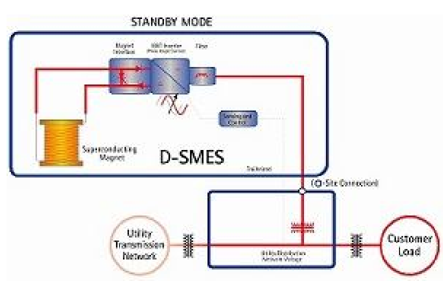

Fig. 3 Schematic diagram of SMES

The magnetic energy stored by a coil of an SMES is given by

$$E = \frac{1}{2} L I^2 \quad (6)$$

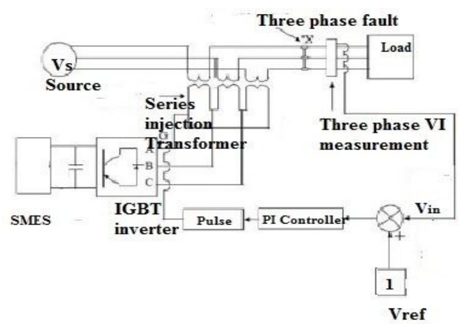

Fig. 4 Schematic diagram of SMES based DVR

IV .PROPOSED CONTROL CIRCUIT

In normal DVR based compensation, downstream fault current was not considered or the DVR was bypassed during that fault. But here along with voltage sag compensation downstream fault current mitigation was also considered. The control scheme for the mitigation of downstream fault current is given below.

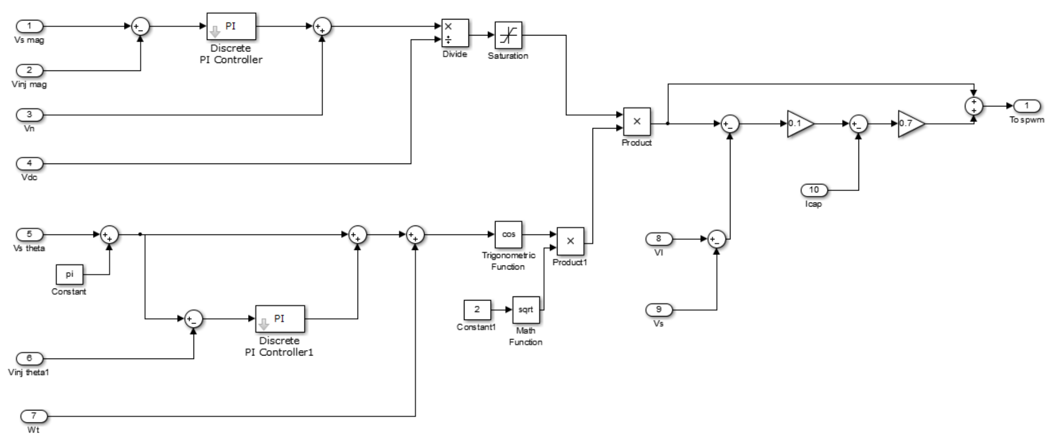

Fig. 5 Control block diagram of mitigation of fault current

The DVR is conventionally bypassed during a downstream fault to prevent potential adverse impacts on the fault and to protect the DVR components against the fault current. A technically elaborate approach to more efficient utilization of the DVR is to equip it with additional controls and enable it also to limit or interrupt the downstream fault currents. A control approach to enable a DVR to serve as a fault current limiter is proposed earlier . The main drawback of this approach is that the dc-link voltage of the DVR increases due to real power absorption during fault current-limiting operation and necessitates a switch to bypass the DVR when the protective relays, depending on the fault conditions, do not rapidly clear the fault.

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The proposed DVR is a multifunctional DVR that is it can mitigate for both voltage sag and downstream fault current . Thus, the mutual effects of these modes on each other must be evaluated. At 15 ms, the system is subjected to a phase-A to phase-B fault with the resistance of 0.8 ohm at 90% of the line length from source side. The fault causes 87% voltage sag at the PCC. At 55 ms, another fault with the resistance of 0.3 on phase-A at 10% length of the cable at load side. The upstream fault is cleared by relays at 93 ms.

V . SIMULINK MODEL AND RESULTS

Using MATLAB, the model of DVR is established, and the simulation tests are performed to evaluate the system performance. A fault is given for a period of 0.4-0.8s. At 0.5s the circuit breaker gets opened and closes on 0.9s. Without using DVR, from the fig. it is clear that, when a fault is applied voltage gets reduced. With DVR when the circuit breaker gets opened, DVR is automatically connected and injects appropriate voltage in proportion to the reduction in voltage and hence get compensated.

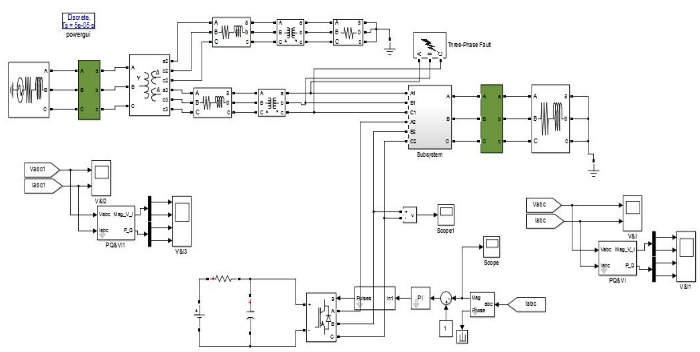

Fig. 6 SMES based DVR

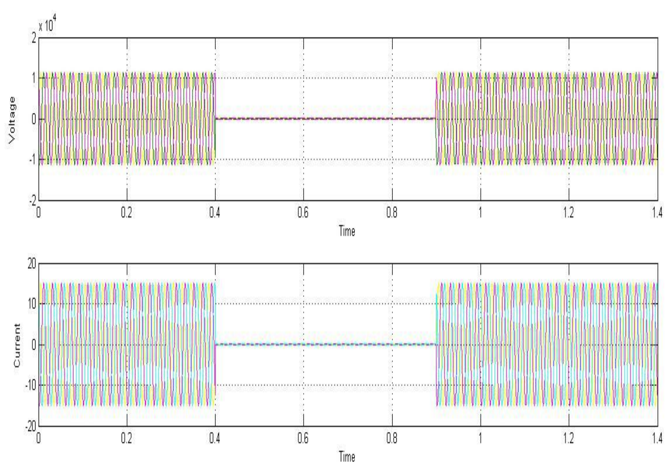

Fig. 7 Simulation results without DVR

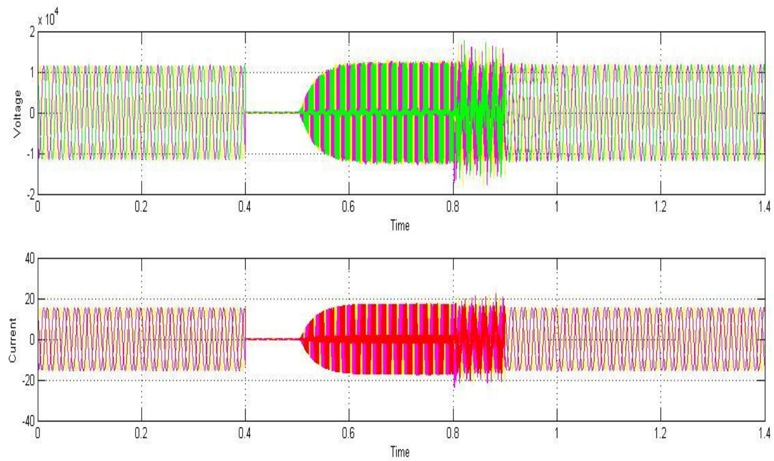

Fig. 8 Simulation results with SMES based DVR

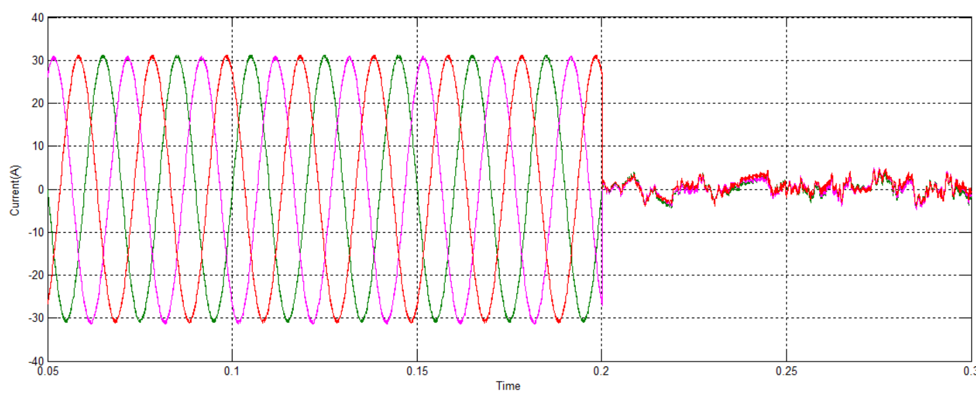

Fig. 9 Mitigation of fault current

VI. CONCLUSION

Due to the characteristic of high energy density and quick response, a superconducting magnet is selected as the energy storage unit to improve the compensation capability of DVR. In addition to that, an auxiliary control strategy for the interruption of downstream fault current in transmission line is introduced. The compensation capability of DVR can be further be improved by using fuzzy controller as feedback controller.

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Appendix

Table I System Parameter

Parameters	Specification
Source Voltage	11 KV
Three winding Transformer	11/110KV
Three phase fault Transition time	0.4- 0.8 sec
Circuit Breaker Transition Time	0.5-0.9 sec
DC link capacitor	750 F